

# The environmental effects in the origin of angular momenta of galaxies

WŁODZIMIERZ GODŁOWSKI

Institute of Physics, Opole University, Opole, Poland

AND

ELENA PANKO

Kalinenkov Astronomical Observatory, Nikolaev State University, Nikolaev,  
Ukraine

AND

PIOTR FLIN

Institute of Physics, Jan Kochanowski University, Kielce, Poland

We study the galaxy alignment in the sample of very rich Abell clusters located in and outside superclusters. The statistically significant difference among investigated samples exists. We found that in contrast to whole sample of cluster, where alignment increase with the cluster richness, the cluster belonging to the superclusters does not show this effect. Moreover, the alignment decreased with the supercluster richness. One should note however that orientations of galaxies in analyzed clusters are not random, both in the case when we analyzed whole sample of the clusters and only clusters belonging to the superclusters. The observed trend, dependence of galaxy alignment on both cluster location and supercluster richness clearly supports the influence of environmental effects to the origin of galaxy angular momenta.

PACS numbers: 98.52.-b;98.65.-r

## 1. Introduction

The problem of the origin of large scale structures is till now one of the most enigmatic ones. It is commonly accepted that presently observed structures originated from almost isotropic distribution in the early Universe. The departure from isotropy, as estimated from CMBR is of the

order of  $\delta\rho/\rho \simeq 10^{-5}$ . About a half century ago the main problems were connected with type of the perturbations, its amplitude and scale (mass or length). Different theories of galaxy origin called scenarios predicted various masses of newly originate structures and various manners in which galaxy gained angular momentum (Peebles 1969, Zeldovich 1970, Sunyaev & Zeldovich 1972, Doroshkevich 1973, Shandarin 1974, Wesson 1982, Silk & Efstathiou 1983, Bower et al. 2005). In some scenarios, the distribution of galaxy angular momenta in structure were random ones, in others perpendicular or parallel to the structure main plane (Peebles 1969, Doroshkevich 1973, Shandarin 1974, Silk 1983, Catelan & Theuns 1996, Li 1998, Lee & Pen 2002, Navarro et al. 2004, Trujillo et al. 2006). In such a manner, the existence or not of the galaxy orientation can be used for testing scenarios of galaxy origin. Because the real location of rotation axes is known for very small number of objects, usually the study of orientation of galaxy planes is performed. In contemporary picture of large scale distribution known as "Cosmic Web" we practically have four components. These are long filaments, walls, voids and the rich, dense regions called galaxy clusters.

In our previous paper (Godłowski & Flin 2010) we studied the orientation of galaxy groups in the Local Supercluster. We found the strong alignment of the major axis of the groups with both direction toward the supercluster centre (Virgo cluster) as well as with line joining two brightest galaxies in the group. The interpretation of these observational facts was the following. The brightest (belived to be the most massive) galaxies of the group originate first. Due to gravitational forces other galaxies are attracted to these ones and a filament is forming. The other possibility is that at the pre-existing filament galaxies are forming. In this direction is going the result of Jones et al. (2010) which interpretet theirs founding that the spins of spiral galaxies located within cosmic web filaments tend to be aligned along the larger axis of the filament, as "fossil" evidence indicating that the action of large scale tidal torques effected the alignments of galaxies located in cosmic filaments.

In the paper of Godłowski et al. (2010), when analizing the sample of 247 rich Abell Clusters, we found that the alignment of member galaxies in rich structures, having more than 100 members, is a function of the group mass. Richer group exhibits stronger galaxy alignment. The change of alignment with the surrounding neighbourhood was observed also in alignment study in void vicinity (Varela et al. 2011), being continuation of earlier study of galaxy orientation in regions surrounding bubble-like voids (Trujillo et al. 2006). They found that disk galaxies around large voids (greater than  $15Mpc/h$ ) present a significant tendency to have their angular momenta aligned with the void's radial direction. The strength of this alignment is dependent on the void's radius and for voids with  $\leq 15Mpc/h$  the dis-

tribution of the orientation of the galaxies is compatible with a random distribution. Varela et al. (2011) found that this trend observed in the alignment of galaxies is similar to that observed in numerical simulations of the distribution of dark matter i.e. in distribution of the minor axis of dark matter halos around cosmic voids, which suggests a possible link in the evolution of both components.

In view of these facts, it is interesting to look if the the cluster belonging to the larger structures exhibit the same type of alignment as whole sample of the clusters. For this reason, we analyze the alignment of the cluster members of galaxies for the clusters belonging to the superclusters. This problem was not investigated till now, although alignment of galaxies in the superclusters was investigated many times. Presence of non-random galaxy spin orientation has been ascertained both in the Local Supercluster (for example MacGillivray et al. 1982, Flin and Godłowski 1986, 1989, 1990, Godłowski 1993, 1994, Kashikawa and Okamura 1992, Aryal and Saurer 2005a, Hu et al. 2006, Aryal, Neupane and Saurer 2008, Aryal, Paudel and Saurer 2008) and in other superclusters, as the Hercules Supercluster, Coma/A 1367 and the Perseus Supercluster (Gregory et al. 1981, Djorgovski 1983, Flin 1988, Garrido et al. 1993, Wu et al. 1997, Cabanela and Aldering 1998, Flin 2001).

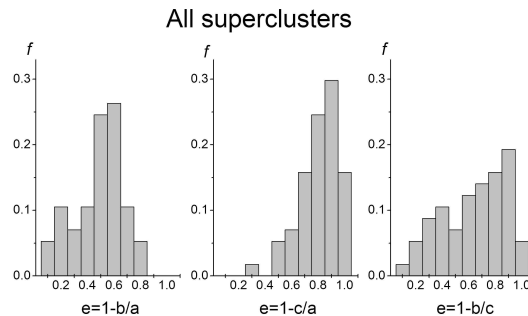


Fig. 1. Ellipticities of the analyzed superclusters

## 2. Observational data

The PF Catalogue of galaxy structures (Panko & Flin 2006) was used as observational basis of the present study. This Catalogue was constructed by finding structures in the Muenster Red Sky Survey (MRSS) (Ungruhe et al. 2003). We used the Voronoi tessellation technique for structure finding.

MRSS is a large-sky galaxy catalogue covering an area of about 5000 square degrees on the southern hemisphere. It is the result of scanning of 217 ESO plates, giving positions, red magnitudes, radii, ellipticities and position angles of about 5.5 million galaxies and it is complete down to  $r_F = 18.3^m$ . As a result we have 6188 galaxy structures called clusters. Using standard covariance ellipse method we determined structure ellipticity and position angles. We chose the sample of 247 very rich clusters, having at least 100 members each, and being identified with one of the ACO clusters (Abell et al. 1989)- see Godłowski et al. (2010) for details. The PF catalogue served also as a basis for supercluster detection. We found 54 superclusters having at least 4 clusters each. As expected, superclusters are rather flat structures (see Fig. 1). We found that 43 from total member of 247 clusters belong to the superclusters and they were chosen for detailed analysis.

Table 1. The frequency of anisotropy of very rich clusters located in superclusters

Richness	The angle P	The angle $\delta_D$	The angle $\eta$
N=4	0.84	0.74	0.84
N=5-7	0.31	0.90	0.79
N=8-10	0.43	0.57	0.43

### 3. Results and analysis

We studied the alignment of galaxies in very rich clusters belonging to superclusters. The study of alignment as usually was done by analyzing the angles connected with the orientation of galaxy plane. These are: the position angle of the great axis of the galaxy image and the angles describing the orientation of the normal to the galaxy planes: polar -  $\delta_D$  and azimuthal  $\eta$ . At first we binned our samples into three bins according to the supercluster richness, These were: superclusters containing only 4 structures, subsample containing 5,6 and 7 structures and finally subsample of superclusters each of them containing 8 and 10 clusters. One should note however that three clusters 0347-5571, 2217-5177 and 2234-5249 have double possible identification with supercluster and these clusters are counted for two bins.

Table 2. The random statistics

Test	$\bar{x}$	$\sigma(x)$	$\sigma(\bar{x})$	$\sigma(\sigma(x))$
$\chi^2$	34.9592	1.2843	0.0406	0.0287
$\Delta_1/\sigma(\Delta_1)$	1.2567	0.0983	0.0031	0.0022
$\Delta/\sigma(\Delta)$	1.8846	0.1027	0.0032	0.0023

At first we study the frequency of alignment of very rich clusters (having 100 and more members) ascribed to supercluster (Tab.1). One can show that

Table 3. The statistics of the observed distributions for real clusters

Test	$P$		$\delta_D$		$\eta$	
	$\bar{x}$	$\sigma(x)$	$\bar{x}$	$\sigma(x)$	$\bar{x}$	$\sigma(x)$
$\chi^2$	38.772	1.574	57.079	6.190	84.656	7.391
$\Delta_1/\sigma(\Delta_1)$	1.797	0.148	3.594	0.385	5.324	0.586
$\Delta/\sigma(\Delta)$	2.339	0.148	4.906	0.407	6.475	0.522

anisotropy decreased with supercluster richness. Moreover, we determined the frequency alignment in the whole sample of 247 very rich Abell clusters. In the whole sample of 247 clusters anisotropy on the distributions of the angle  $P$  was observed in 38% clusters, while galaxy plane anisotropy was noted in 85% and 77% clusters in the case of the angle  $\delta_D$  and the angle  $\eta$  respectively. For the sample of galaxies belonging to the supeclusters we

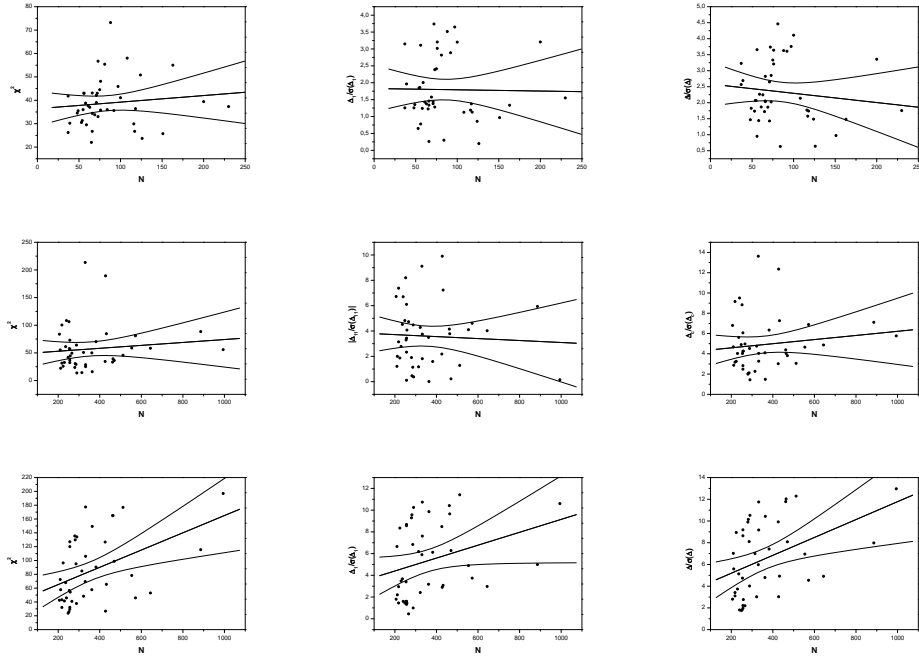


Fig. 2. The relation between the number of galaxies in the cluster  $N$  and the value of analyzed statistics ( $\chi^2$  - left panel,  $\Delta_1/\sigma(\Delta_1)$  - middle panel,  $\Delta/\sigma(\Delta)$  - right panel) for the position angles  $p$  (upper panel),  $\delta_D$  angles (middle panel) and  $\eta$  angles (bottom panel) - equatorial coordinates. The bounds error, at confidence level 95%, were presented as well.

observed anisotropy in 55% clusters in the case of position angles  $P$  and in 78% and 76% of the clusters in the case of the angle  $\delta_D$  and the angle  $\eta$  respectively.

The observed anisotropy is significantly greater when we analyzed the spatial orientation of galaxy plane ( $\delta_d$  and  $\eta$  angles) than in the case of position angles  $p$ . In our opinion this is due to incorrectly assumed shapes of galaxies. This problem was analyzed in details by Godłowski, Ostrowski (1999), Godłowski et al. (1998), Baier et al. (2003). The work of Godłowski and Ostrowski (1999) was based on the Tully's NGC Catalog (1988). In this catalog during calculating galaxy inclination angles, Tully assumed that the "true" ratio of axes of galaxies is 0.2, which is a rather poor approximation, especially for non-spiral galaxies (Godłowski 2011). For our present analysis this effect is not so important because in the case of analysis of spatial orientation of galaxy planes our interest is how alignment is changing with belonging of the clusters to the supercluster and with supercluster richness.

Now we decided to analyze the alignment in the cluster belonging to superclusters in more details. Hawley & Peebles (1975) analyzed the distributions of position angles using  $\chi^2$  test, Fourier tests and autocorrelation test. Since Hawley & Peebles (1975) paper this method was accepted as standard method for analysis of a galactic alignment. One should note that there are several modifications and improvement of original Hawley & Peebles (1975) methods (Flin & Godłowski 1986, Kindl 1987, Godłowski 1993, 1994, Aryal & Saurer 2000, Godłowski et al. 2010) Godłowski (2011a) performed a deeper improvement of the original Hawley & Peebles (1975) method and showed its usefulness for analysis of galactic orientations in clusters. In the paper of Godłowski (2011a) the mean values of analyzed statistics was computed. The null hypothesis  $H_0$  was that the mean value of the analyzed statistics was as expected in the cases of a random distribution of analyzed angles. The results was compared with theoretical predictions as well as with results obtained from numerical simulations.

Table 4. The results of the linear regression analysis - value of analyzed statistics on function of the cluster richness for the clusters belongin to the superclusters.

angle	$\chi^2$		$\Delta_1/\sigma(\Delta_1)$		$\Delta/\sigma(\Delta)$	
	$a \pm \sigma(a)$	$b \pm \sigma(b)$	$a \pm \sigma(a)$	$b \pm \sigma(b)$	$a \pm \sigma(a)$	$b \pm \sigma(b)$
$P$	$0.028 \pm 0.039$	$36.4 \pm 3.7$	$-0.0004 \pm 0.0037$	$1.83 \pm 0.15$	$-0.0029 \pm 0.0037$	$2.58 \pm 0.34$
$\delta$	$0.026 \pm 0.037$	$47.7 \pm 14.6$	$-0.0008 \pm 0.0023$	$3.87 \pm 0.91$	$0.0020 \pm 0.0024$	$4.18 \pm 0.96$
$\eta$	$0.125 \pm 0.040$	$40.2 \pm 15.7$	$0.0060 \pm 0.0030$	$3.21 \pm 1.17$	$0.0082 \pm 0.0028$	$3.54 \pm 1.13$

Following Godłowski (2011a) method now we analyzed our sample of 43 clusters belonging to the superclusters in details. Because of small number of galaxies in some clusters we performed 1000 simulations of the distribu-

Table 5. The statistical analysis: value of analyzed statistics for different superclusters richness.

angle	Test	$N = 4$	$N = 5 - 7$	$N = 8 - 10$
$P$	$\chi^2$	$43.30 \pm 2.42$	$34.99 \pm 2.11$	$36.65 \pm 1.55$
	$\Delta_1/\sigma(\Delta_1)$	$1.99 \pm 0.25$	$1.50 \pm 0.16$	$1.89 \pm 0.32$
	$\Delta/\sigma(\Delta)$	$2.57 \pm 0.23$	$2.08 \pm 0.18$	$2.42 \pm 0.36$
$\delta_D$	$\chi^2$	$54.52 \pm 10.69$	$48.68 \pm 4.57$	$89.07 \pm 18.56$
	$ \Delta_{11}/\sigma(\Delta_{11}) $	$3.13 \pm 0.63$	$2.76 \pm 0.57$	$6.41 \pm 0.84$
	$\Delta_c/\sigma(\Delta_c)$	$4.76 \pm 0.72$	$4.40 \pm 0.34$	$6.97 \pm 1.09$
$\eta$	$\chi^2$	$83.60 \pm 12.09$	$95.57 \pm 9.74$	$43.01 \pm 5.44$
	$\Delta_1/\sigma(\Delta_1)$	$5.43 \pm 0.86$	$5.83 \pm 0.71$	$2.02 \pm 0.29$
	$\Delta/\sigma(\Delta)$	$6.30 \pm 0.88$	$7.31 \pm 0.66$	$3.19 \pm 0.38$

tions of the position angles in 43 fictious clusters, each cluster with number of members galaxies the same as in the real cluster. In the Tab.2 we present average values of the analyzed statistics, theirs standard deviations, standard deviations in the sample and theirs standard deviations for distribution of  $P$  angles. The applied statistics in details were presented in our previous papers (Godłowski et al. 2010 and Godłowski 2011a). We compared results obtained for real sample of our 43 clusters with that obtained from numerical simulations.

For the sample of all 43 clusters located in superclusters the distributions of the position angles of members galaxies in the cluster are anisotropic and the departure from the isotropy is greater than  $3\sigma$  (see Tab. 2 and Tab.3). For the angles which give the spatial orientation of galaxy planes ( $\delta_d$  and  $\eta$  angles) the anisotropy is even greater but one should remember the above problem with approximation of the "true" ratio of axes of galaxies as 0.2.

The main point of our study is connected with the trends appearing in the data. In the analyzed sample of 43 galaxies we do not observe the effects connected with cluster richness (Fig.2, Tab.4) which is significantly different from result obtained by Godłowski et al. 2010 for whole sample of 247 rich Abell clusters. We suppose that such differences is probably due to environmental effects during superclusters forming.

In the Tab.5 we presented value of analyzed statistics for different superclusters richness. Generally the anisotropies decreased with the superclusters richness. Anisotropy for the angles  $P$  and  $\delta_d$  seems to increase again for very rich supercluster. One should note however, that subsample of supercluster richness 8 – 10 contain significantly less clusters (7) in comparison to the poorer superclusters and moreover two cluster belonging to this bin have possible double identifications. Result of linear regresion between values of analyzed statistics and supercluster richness presented on the Fig.3 and in Tab.6 generally confirmed above conclusion, with exception for  $\delta_d$  angle where influence of the 8 – 10 bin is significant. Because our binned analysis

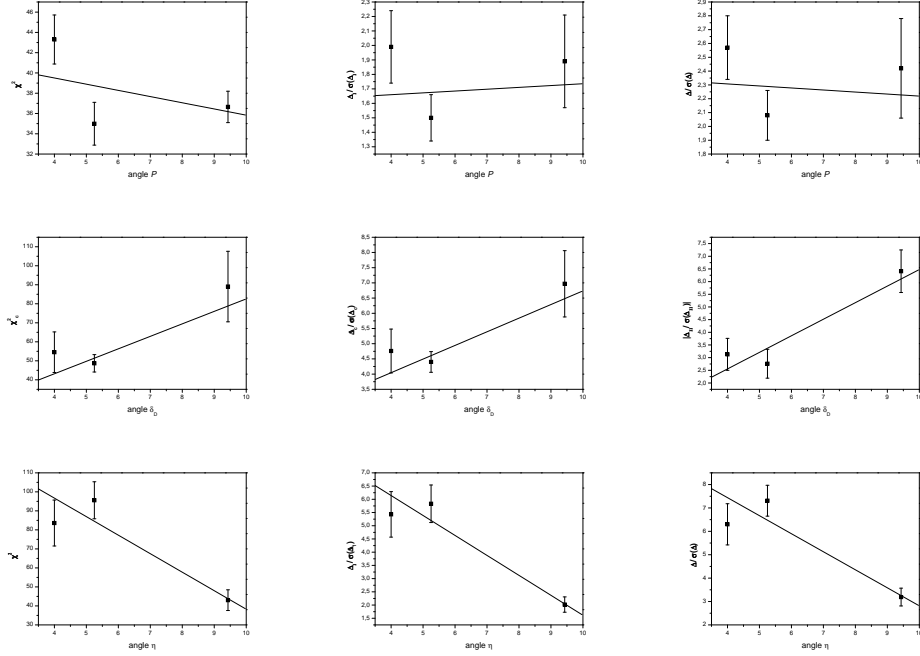


Fig. 3. The result of the regression analysis between value of statistics ( $\chi^2$  - left panel,  $\Delta_1/\sigma(\Delta_1)$  - middle panel,  $\Delta/\sigma(\Delta)$  - right panel) and the number of clusters in superclusters for the position angles  $p$  (upper panel),  $\delta_D$  angles (middle panel) and  $\eta$  angles (bottom panel) - equatorial coordinates.

is based only for 3 bins it is difficult to decide about statistical significance of this results. For this reason we repeat our analysis for not binned sample of 46 clusters (3 of them have possible double identifications). Analysing statistics  $T = \frac{a}{\sigma(a)}$  which has Student's distribution with  $n - 2$  degrees of freedom, we conclude that only in the case of the  $\eta$  angle decreasing the anisotropy with the supercluster richness is statistically significant on the level of 0.05.

#### 4. Discussion and conclusions

We investigated sample of 43 rich Abell galaxy cluster belonging to the supercluster and having at least 100 members in the considered area. As expected, the analysed superclusters are rather flat structures. We found that orientation of galaxies in the analysed cluster are not random. Godłowski



Table 6. The results of the linear regression analysis - value of analyzed statistics on the function of supercluster richness

angle	$\chi^2$		$\Delta_1/\sigma(\Delta_1)$		$\Delta/\sigma(\Delta)$	
	$a \pm \sigma(a)$	$b \pm \sigma(b)$	$a \pm \sigma(a)$	$b \pm \sigma(b)$	$a \pm \sigma(a)$	$b \pm \sigma(b)$
$\bar{P}$	$-0.61 \pm 0.46$	$41.9 \pm 3.5$	$0.014 \pm 0.074$	$1.61 \pm 0.43$	$-0.016 \pm 0.080$	$2.39 \pm 0.45$
$\delta$	$6.57 \pm 3.94$	$16.9 \pm 21.2$	$0.656 \pm 0.191$	$-0.08 \pm 1.14$	$0.445 \pm 0.240$	$2.27 \pm 1.31$
$\eta$	$-9.74 \pm 1.97$	$135. \pm 16.$	$-0.756 \pm 0.131$	$9.14 \pm 1.13$	$-0.770 \pm 0.139$	$10.5 \pm 1.1$

et al. (2011) found that for the rich Abell cluster alignment increases with the cluster richness. In contrast, the cluster belonging to the superclusters does not show such effect. The alignment in poor supercluster is greater than in the case of rich one. The obtained results, which show the dependence of galaxy alignment on both the cluster location inside or outside the supercluster and the supercluster richness clearly support the influence of environmental effects to the origin of galaxy angular momenta. In a very simple and naive picture, if the alignment of galaxies is primordial, the strongest effect should be observed in small structures. However, in the present moment we do not have such data. We considered only really very rich clusters and looked for trends. It could be accepted that gaining of angular momenta for galaxies in structure is a rather complicated problem, in which several mechanisms played roles. In some cases the angular momentum of galaxies is due to local anisotropic collapse of protostructures, in other ones due to tidal torque mechanism. Moreover, cluster merging introduces additional factors influencing the observed distribution of galaxy angular momenta. This suggests that the environment played a crucial role in the origin of galaxy angular momentum. Our result is preliminary because our investigations were based on a sample of only very rich clusters and will be continued with analysis of the structures with various richness taken into account. Fortunately, PF catalogue will allow us to perform such analysis.

## REFERENCES

- [1] Abell, G.O., Corwin, H.G., Jr., Olowin, R.P., 1989, ApJS, 70, 1
- [2] Aryal, B., Saurer, W., 2000, A&A, 364, L97
- [3] Aryal, B., Neupane, D., Saurer, W., 2008 A&SS 314, 177
- [4] Aryal, B., Paudel, S., Saurer, W., 2008 A&A, 479, 397
- [5] Aryal, B., Saurer, W., 2005 A&A, 432, 431
- [6] Baier, F. W., Godłowski, W., MacGillivray, H. T. 2003, A&A, 403, 847
- [7] Bower, R. G., Benson, A.J., Malbon, R., Helly, J., Frenk, C. S., Baugh, C. M., Cole, S., Lacey, C. G. 2006, MNRAS, 370, 645

- [8] Cabanella, J.E., Aldering, G., 1998 AJ 116, 1094
- [9] Catelan, P., Theuns, T. 1996 MNRAS, 282, 436
- [10] Djorgovski, S. 1983, ApJ, 274, L7
- [11] Doroshkevich, A. G. 1973, ApL, 14, 11
- [12] Flin, P. 1988 MNRAS 235, 857
- [13] Flin, P., 2001 MNRAS 325, 49
- [14] Flin, P., Godłowski, W. 1986, MNRAS, 222, 525
- [15] Flin, P., Godłowski, W., 1989 Sov. Astron. Lett. 15, 374 (Pisma w Astro. Zhurnal 15, 867)
- [16] Flin, P., Godłowski, W., 1990 Sov. Astron. Lett. 65, 209 (Pisma w Astro. Zhurnal 16, 490)
- [17] Garrido J.L., Battaner, E., Sanchez-Saavedra, M.L., Florido, E., 1993 A&A 271, 84
- [18] Godłowski, W. 1993, MNRAS, 265, 874
- [19] Godłowski, W. 1994, MNRAS, 271, 19
- [20] Godłowski, W. 2011, IJMPD 20, 1643
- [21] Godłowski, W., 2011a, arXiv:1110.2245
- [22] Godłowski, W., Baier, F.W. MacGillivray, H.T., 1998, A&A 339, 709
- [23] Godłowski, W., Flin, P., 2010, ApJ 708, 902
- [24] Godłowski, W., Ostrowski, M., 1999, MNRAS 303, 50
- [25] Godłowski, W., Piwowska, P., Panko, E., Flin, P., 2010, ApJ 723, 985
- [26] Gregory, S.A., Thompson, L.A., Tifft, W.G., 1981 ApJ 243, 411
- [27] Hawley, D. I., Peebles, P. J. E. 1975, AJ, 80, 477
- [28] Hu F.X., Wu G.X., Song G.X., et al. 2006 A&SS 302, 42
- [29] Jones, B., van der Waygaert R., Aragon-Calvo M., 2010 MNRAS, 408, 897
- [30] Kashikawa, N., Okamura, S., 1992 PASJ 44, 493
- [31] Kindl, A. 1987, AJ 93, 1024
- [32] Lee, J., Pen, U. 2002, ApJ, 567, L111
- [33] Li, Li-Xin., 1998, Gen. Rel. Grav., 30, 497
- [34] MacGillivray, H.T., Dodd, R.J., McNally, B.V., Corwin, Jr. H.G., 1982, MNRAS, 198, 605
- [35] Navarro, J. F., Abadi, M. G., Steinmetz M. 2004, ApJ, 613, L41
- [36] Panko, E., Flin, P., 2006, Journ. Astro. Data 12,1
- [37] Peebles, P.J.E. 1969, ApJ, 155, 393
- [38] Shandarin, S.F. 1974, Sov. Astr. 18, 392
- [39] Silk, J., Efstathiou, G. A. 1983, The Formation of Galaxies, Fundamentals of Cosm. Phys. 9, 1
- [40] Sunyaev, A. R., Zeldovich, Ya. B., 1972 A&A, 20, 189
- [41] Trujillo, I., Carretro, C., Patiri, S.G., 2006, ApJ 640, L111

- [42] Tully, R. B., Nearby Galaxy Catalog, Cambridge 1988
- [43] Ungruhe, R., Seitter, W., Durbeck, H., 2003, Journ. Astr. Data, 9.1
- [44] Varela, J. Rios, J.B., Trujillo, I., 2011, astro-ph 1109.2056
- [45] Wesson, P. S. 1982, Vistas Astron., 26, 225
- [46] Wu G.X., Hu F.X., Su H.J., Liu Y.Z., 1997 A&A, 323, 317
- [47] Zeldovich, B. Ya. 1970, A&A, 5, 84